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CHAPTER 1
INTRODUCTION

During past few years, wireless communication which includes the fixed and the mobile data traffic has increased rapidly. As the number of devices and users increases, it is expected to exchange very large amount of data and to handle the data traffic efficiently, which is a big challenge. Some advance technology is required to fulfill these needs.[1] The fifth generation wireless communication system is a new emerging technology in recent years to address these issues, since it increases the data rate and enhances throughput. High data rate, high capacity, low complexity, and low latency communication system is expected to provide us with 5G technology. To fulfill all these demands different new technologies in 5G has been introduced.

Multiple input and multiple output (MIMO) is one of the technology that provides high data rate and increases the throughput. MIMO consist of multiple antennas at the transmitter and at the receiver. Each transmitting antenna can send the signal to each receiving antenna.[2] Due to the use of multiple antennas, multiple data stream can be transmitted simultaneously using spatial multiplexing, in order to increase the data rate. MIMO can be categorized as: single user and multi user. SU-MIMO consists of single user and all the data are transmitted to single user only. MU-MIMO consists of multiple users and transmitter can send separate data stream to different users simultaneously.

If a base station(BS) equipped with a hundred or more antennas and ten or more than ten number of users in the same time frequency resource, serves simultaneously, then the MU-MIMO is known as Massive MIMO system.[3] Higher spectral and energy efficiency can be achieved by using large antenna array. Using massive MIMO data throughput can be increased many fold compared to MIMO. It is because as the number of antennas in a system increases, more number of data signal can be transmitted to the user, which in turn increases the data rate.[4]

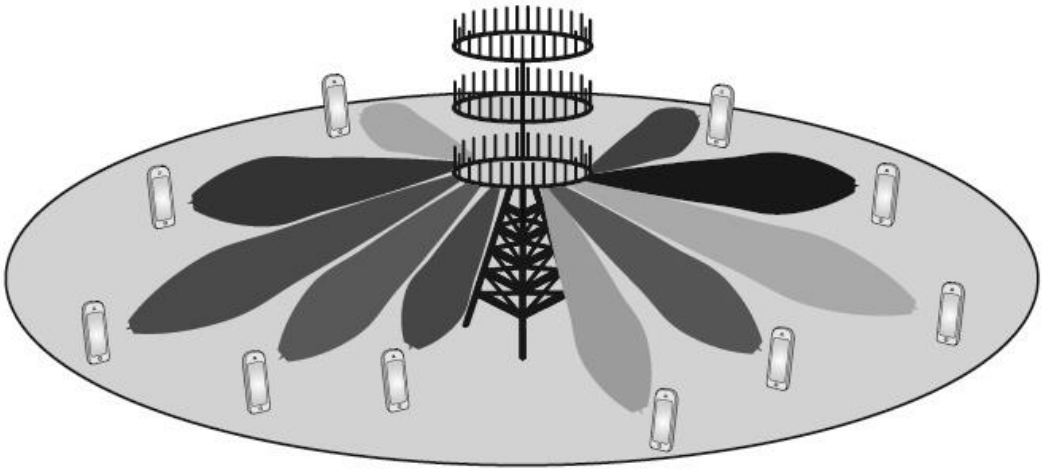

Fig.1 Massive MIMO system (M.Ramesh, C.Geetha Priya and V.P.M.B.Aarthi Alais, [20])

System model

In massive MIMO system model there is one base station and K number of active users. There are M numbers of antenna at the base station and there can have single-antenna or multiple antennas for each user.[5] Generally, Massive MIMO works in time division duplex mode. In massive MIMO there are mainly three operations: channel estimation, uplink data transmission, and downlink data transmission.

Channel estimation

Channel estimation is a technique to characterize the channel. The base station requires the channel state information for detection of the signals in the uplink and for precoding of the signals in the downlink.[6] To obtain CSI uplink training is required. Ideally pilot sequences which are orthogonal are assigned to each user and each user transmits this pilot sequence to the base station and then BS estimate the channel or channel matrix based on this received pilot signals.

Uplink Data Transmission

In the uplink transmission, the transmission of data is from the user to the base station. So in massive MIMO, in the same time-frequency resource the K users transmit their data to the base station. Then to detect signals transmitted from all users, the BS uses the linear detection techniques together with the channel estimates. Steps involved for uplink operation: [7].

- Firstly Encoding on the data.
- Each user transmits the pilot sequences and uplink data sequences to the BS.

- After receiving from all the user, the sum of the data sequences the base station then estimates the channel.
- Original individual data streams are recovered using detection techniques.
- The received signal vector can be expressed as.

$$Y_{ul} = \sqrt{\rho}_{ul} H X_{ul} + n_{ul}$$

Where, Y_{ul} is received signal at BS, H is uplink channel matrix, X_{ul} is signal vector from all users, n_{ul} is noise vector and $\boldsymbol{\rho}_{ul}$ is uplink transmitted power

Downlink Data Transmission

In the downlink, transmission is from the base station to the users. In massive MIMO, in the same time-frequency resource, the BS transmits the signals to the K users. The BS creates M precoded signals which are given to M antennas of BS. Steps involved for downlink operation: [8]

- Beamforming: Beamforming is a signal processing technique used in antenna arrays for directional signal transmission or reception. Using beamforming technique, the data sequences are transmitted from the base station to the intended users only, in same time frequency resource.
- Precoding: The precoded signal is the linear combination of the symbols that is intended for the users and transmitted from M antennas of BS to K users, Then, precoded signal vector x is x = Wq, Where W is precoding matrix and q symbol intended for K users.
- The received signal vector can be expressed as.

$$Y_{dl} = \sqrt{\rho}_{dl} H^T X_{dl} + n_{dl}$$

Where, Y_{dl} is received signal vector at user, H^T is downlink channel matrix, X_{dl} is signal vector from BS, n_{dl} is noise vector and $\boldsymbol{\rho}_{dl}$ is downlink transmitted power

Potential of Massive MIMO

Some key potentials of a massive MIMO system are as[4, 8, 9]:

- Due to the use of spatial multiplexing concept in massive MIMO the capacity can increases 10 times or more than that.
- Massive MIMO enhances the spectral efficiency
- It also improves the energy efficiency of the order of 100 times. In massive MIMO large number of antenna are used, so energy can be focused with extreme sharpness.
- Massive MIMO systems can be designed with low-cost and low-power components.

- Massive MIMO increases the robustness against jamming and unwanted man made interference.
- Massive MIMO reduces latency on the air interface.

Challenges of Massive MIMO

Various challenges of massive MIMO are highlighted as[4,8,10]:

- Channel Reciprocity: In TDD, by exploiting the channel reciprocity, the transmitter can estimate the downlink channel from the uplink channel just by taking transpose of channel matrix. The channel between BS and user, in uplink and downlink may not be reciprocal, because of improper calibration. If proper calibration is not there then some effective techniques are needed to be used.
- Low cost hardware:- Due to the use of large number of A/D, D/A converters, RF chains and many other devices in massive MIMO systems, the cost goes very high so investigation on low cost hardware is required
- Pilot Contamination: In massive MIMO system each user is assigned with limited number of orthogonal pilot sequence. So reuse of pilot sequences among different cell is required. Reusing of pilot sequences from one cell to other causes interference which can be termed as Pilot Contamination. So effective techniques are required to mitigate the pilot contamination.

CHAPTER 2
REVIEW OF LITERATURE

In 2014, E. G. Larsson et al. present a paper that focuses on overview of massive MIMO concepts. In this paper various potential of massive MIMO in terms of efficiency, capacity, reliability etc were highlighted and also covered the challenges of massive MIMO. [4]

In 2014, Ke Li et al. proposed an estimation method that uses joint channel processing together with interference cancellation method, in order to mitigate pilot contamination. To improve the overall performance firstly users that causes high interference in neighbouring cells, were identified and then joint channel processing was performed. Single-cell MMSE channel estimation, and the multicell MMSE channel estimation were compared and concluded that compared to single cell MMSE the performance of proposed scheme is higher.[6]

In 2015, X. Zhu et al. proposed smart pilot assignment (SPA) scheme in order to improve the performance under severe pilot contamination. In SPA method the user having the worst channel quality was assigned with the pilot sequence with the smallest inter-cell interference Simulation results verify that the uplink SINR of user was improved by 2 dB. [7]

In 2016, A. Yang et al. analyzed the uplink massive MIMO, ergodic achievable rate. In this MRC detector and ZF detector were compared and simulation result shows that ZF detector achieve higher spectrum efficiency compared to MRC. The expressions for MRC detector and ZF detector to obtain ergodic achievable rate for large number of users were derived.[11]

In 2016, O. Elijah et al. provided a survey on pilot contamination and highlighted the different sources of it. The paper provides different mitigation techniques using pilot-based approach and subspace-based approach. In pilot based approach, in each cell the transmission of pilot signal is done by shifting location of the pilot in frames. Sub space estimation technique uses EVD on covariance matrix.[12]

In 2016, R. Sultan et al. studied full duplex (FD) massive MIMO systems and investigated the differences in terms of the power received, multiuser interference and co-channel interference, between the different transmission modes. Also uplink and downlink capacities for full duplex and half duplex were derived and analyzed the performance for both the modes of transmission. The result showed that if the co-channel interference value was below threshold then compared to half duplex, the downlink rate for full duplex was higher, , after setting the number of transmitting antennas and also, it was shown that if the self interference cancellation is below a certain threshold then compared to half duplex, the uplink rate for full duplex was higher, after setting the number of transmitting antennas.[14]

In 2017, Y. Li et al. studied the ergodic achievable rate of the Full Duplex small cell systems with massive MIMO and linear processing, under imperfect channel estimation and hardware impairments. The expressions of the achievable rate for both the ZF and MRT/MRC processing were derived and used to analyzed the effect of the number of antennas and the hardware imperfection on the self-interference (SI). Two power-allocation algorithms: sequential convex approximation technique and the fractional programming technique for the uplink user and Downlink of the Full duplex BS were proposed to maximize the Spectral efficiency and the Energy efficiency.[15]

In 2017, M.L Rawi et al. investigated using Nakagami-m fading channel, the performance of massive MIMO uplink system. In this maximum ratio combining detection technique and zero forcing detection technique were analyzed and compared. The results showed that with increase in antenna at base station and with increase in value of m, the SE increases. [16]

In 2017, E. Ali et al. presented a review paper on beamforming techniques of massive MIMO and highlighted the importance of beamforming techniques. This paper includes the different classifications of beamforming techniques, and compares different techniques in terms of capacity and interference. [17]

In 2017, H. Zhi et al. proposed two precoding schemes one is MRCwith BS cooperation and ZF with BS cooperation in order to improve the performance. In both the methods, CSI of cell other then target cell is used to reduce the inter cell interference. Also the expressions were derived for achievable sum rate per user, using different uplink pilot reuse factors. The

achievable rate of MRC-BSC and single cell MRC precoding and also for ZF-BSC and ZF were simulated and compared. The result shows that ZF-BSC improves the performance.[18]

In 2018, F. Figueiredo et al. presented an estimation method consider Rayleigh fading channels. In this prior assumption is not made about the large scale fading coefficient of interfering cell and performance of proposed estimator were analyzed under pilot contamination the interference term has been removed using ML estimator. An approximate mean squared error expression was obtain to mitigate pilot contamination. [24]

In 2018, N. Fatima et al. provided a survey paper on different single-cell and multi-cell linear precoding techniques. Different classical precoding techniques were reviewed and compared for single cell. Due to pilot contamination in multi cell, estimation error is viewed in massive MIMO. So advance precoding techniques such as H-infinity, Max-SLNR , Hybrid analog–digital precoding technique, with and without the cooperation were reviewed. [25]

In 2018, P. Rayi et al. proposed a paper that showed the impact of perfect CSI and imperfect CSI on the Spectral efficiency. Analysis of spectral efficiency was done using zero-forcing precoding, maximum ratio combing precoding. In proposed scheme for channel estimation approximate half block is used as coherence data block and remaining blocks used for training. The expressions for optimization of spectral efficiency and energy efficiency were derived for single and multi-cell. It was observed that with imperfect CSI, the spectral efficiency decreased to a lower value.[26]

In 2018, K. Bangash et al. proposed an efficient low-complexity algorithm to estimate channel. This algorithm was based on joint Singular Value Decomposition (SVD) and Iterative Least Square with Projection (SVD-ILSP) that overcomes the drawback of existing SVD-based semi-blind channel estimation scheme. With proposed scheme the deviation reduces, channel estimation accuracy improves, pilot contamination impact reduces and o accurate CSI with low computational complexity could be obtain.[27]

In 2018, R. Chataut et al. proposed an uplink detection method that is more efficient and less complex in computation. The proposed algorithm was compared with convention approximate message passing algorithm, zero forcing and MMSE technique. Bit error rate

and computational complexity was simulated using MATLAB and compared with existing tecnology. [28]

In 2018, N. Nugyen et.al proposed two artificial noise aided scheme for secure massive MIMO. Artificial noise were used into downlink training signal in the first scheme that prevent the eavesdropper to obtain correct CSI. Artificial noise were used in both training and data transmission phase in second scheme. Optimized power allocation algorithms were also proposed to enhance the secrecy capacity. Secrecy rate were obtain under imperfect CSI and using precoding technique. [33]

In 2019, T. Yang et.al provided the analysis of secrecy capacity under imperfect CSI. An expression for secrecy capacity were derived under imperfect CSI and performance of the system were analyzed. Also a new channel estimation technique was proposed, which reduce the effect of imperfect CSI on system secrecy performance.[34]

In 2019 Y. Wu et.al studied the design of secure massive MIMO and observed that decreasing the desired user's signal power would reduce the eavesdropper attack effect. Using this concept proposed a data aided secure downlink transmission method and obtained the achievable secrecy sum rate expression for the proposed method. [35]

RATIONALE

Massive MIMO system could work in single cell or multi- cell environment. For estimation of channel, the pilot signal has to be transmitted and due to limited number of pilot signals, it is required to re use them from one cell to another. This causes the interference termed as *pilot contamination*. Due to this estimation of channel will be contaminated. Downlink precoding based on contaminated estimation of channel will result in channel error and reduces the efficiency or sum rate. Similarly, uplink detection based on contaminated channel will degrade the system performance. So, techniques are required to mitigate the effect of pilot contamination. In massive MIMO, ideally, perfect CSI is not available and due to hardware impairment channels are no longer reciprocal, termed as *channel non-reciprocity*. This affects the performance of uplink and downlink massive MIMO. So, techniques are required to improve the performance of the system under this condition.

In massive MIMO, pilot contamination attack can be performed by active eavesdropper, which results in contaminated estimation of channel and also eavesdropper can decode the information which is not intended to it, by knowing the channel information. So, in massive MIMO physical layer security is also required to enhance the system performance.

CHAPTER 3

OBJECTIVES

3.1 OBJECTIVES

1. **Comparative analysis through simulation of different channel estimation techniques for developing efficient and optimize channel estimation for massive MIMO**
    - Channel estimation through different technique such as zero forcing, MMSE in single cell and multi cell environment will be analyzed to reduce the error and to mitigate the pilot contamination effect.

2. **Performance analysis of uplink massive MIMO using different detection techniques and develop efficient simulation model to improve the sum rate and reduce bit error rate.**
    - Different detection techniques such as matched filter, zero forcing, MMSE will be simulated to reduce the interference. Detection techniques will be analyzed under perfect and imperfect CSI.

3. **Performance analysis of downlink massive MIMO using different precoding techniques and develop efficient simulation model to improve the sum rate and reduce bit error rate.**
    - Different precoding techniques such as zero forcing, MMSE will be analyzed and simulated for single cell and multi cell under perfect and imperfect CSI to improve the spectral efficiency.

4. **To enhance the physical layer security of massive MIMO**.
    - Secrecy capacity in the presence of active eavesdropper will be analyzed and will try to develop a method to increases the secrecy capacity under imperfect CSI.

5. **To maximize the spectral efficiency of massive MIMO in full duplex mode.**
    - The spectral efficiency of full duplex massive MIMO using linear processing technique for uplink and downlink under perfect and imperfect channel estimation shall be obtained.

CHAPTER 4
METHODOLOGY

4.1 PROPOSED METHODOLOGY

The proposed methodology to achieve the objectives is as follows:

4.1.1 Comparative analysis through simulation of different channel estimation techniques for developing efficient and optimize channel estimation for massive MIMO.

Analysis and simulation of various channel estimation methods of massive MIMO using MATLAB tool, so as to develop and propose an optimum channel estimation method considering single cell and multi cell scenario, to improve the system performance. Proposed channel estimation will try to mitigate pilot contamination. Result of existing and proposed work shall be compared to draw conclusion.

4.1.2 Performance analysis of uplink massive MIMO using different detection techniques and develop efficient simulation model to improve the sum rate and reduce bit error rate.

Analysis and simulation of various uplink detection technique of massive MIMO using MATLAB tool, so as to develop and propose an efficient uplink model using Simulink to reduce the bit error rate and to improve the sum rate. Proposed uplink detection technique shall be analyzed under perfect CSI (channel state information) and imperfect CSI. Result of existing and proposed work shall be compared to draw the conclusion.

4.1.3 Performance analysis of downlink massive MIMO using different precoding techniques and develop efficient simulation model to improve the sum rate and reduce bit error rate.

Analysis and simulation of various downlink precoding technique of massive MIMO using MATLAB tool, so as to develop and propose an efficient downlink model using Simulink, to reduce the bit error rate and to improve the sum rate. Proposed downlink technique shall be analyzed under perfect CSI and imperfect CSI. Result of existing and proposed work shall be compared to draw the conclusion.

4.1.4 To enhance the physical layer security of massive MIMO.

Analysis and simulation of the methods for secure massive MIMO using MATLAB tool, so as to develop and propose an efficient method that will enhance the secrecy capacity of the system. Proposed method shall be analyzed under perfect CSI and imperfect CSI considering active eavesdropper. Result shall be compared to draw the conclusion.

4.1.5 To maximize the spectral efficiency of massive MIMO in full duplex mode.

Analysis and simulation of the different methods to improve the spectral efficiency using MATLAB tool considering half duplex and full duplex mode, so as to develop and propose an efficient method that will maximizes the spectral efficiency of the full duplex massive MIMO system. Proposed method will be evaluated using linear uplink and downlink processing under perfect CSI and imperfect CSI. Result shall be compared to draw the conclusion.

4.2 TOOL

There are various products or tools available for performance analysis of 5G. Such as Network Simulator, GNU Octave, SciLab, MATLAB for analysis & evaluation of our results. For proposed research work, MATLAB and Simulink will be prefer.

MATLAB (matrix laboratory) is a fourth-generation high-level programming language and interactive environment for numerical computation, visualization and programming. MATLAB is developed by MathWorks. It allows matrix manipulations; plotting of functions and data; implementation of algorithms; creation of user interfaces; interfacing with programs written in other languages, including C, C++, Java, and FORTRAN; analyze data; develop algorithms; and create models and applications. It has numerous built-in commands and math functions that help you in mathematical calculations, generating plots, and performing numerical methods.

The basic features of MATLAB :-

It is a high-level language for numerical computation, visualization and application development.

It also provides an interactive environment for iterative exploration, design and problem solving.

It provides vast library of mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration and solving ordinary differential equations.

It provides built-in graphics for visualizing data and tools for creating custom plots.
MATLAB's programming interface gives development tools for improving code quality maintainability and maximizing performance.
It provides tools for building applications with custom graphical interfaces.

Simulink is a graphical extension to MATLAB for modeling and simulation of systems. It is a block diagram environment for multidomain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

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